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THE EFFECTS OF SCHEDULE HISTORY AND THE OPPORTUNITY FOR ADJUNCTIVE RESPONDING ON BEHAVIOR DURING A FIXED-INTERVAL SCHEDULE OF REINFORCEMENT

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The effects of schedule history and the availability of an adjunctive response (polydipsia) on fixed-interval schedule performance were investigated. Two rats first pressed levers under a schedule of food reinforcement with an interresponse time greater than 11 s, and 2 others responded under a fixed-ratio 40 schedule. All 4 were then exposed to a fixed-interval 15-s schedule. Water was continuously available under these conditions, but after responding became stable on the fixed-interval schedule, access was experimentally manipulated. With water freely available, subjects did not display characteristic fixed-interval response rates and patterns (i.e., scalloping or break-and-run). Instead, they exhibited predictable, stable patterns of behavior as a function of their schedule histories: Subjects with the interresponse-time history exhibited low response rates, and those with the fixed-ratio history exhibited high rates. Manipulating the amount of water available resulted in marked changes in response rates for rats with the interresponse-time history but not for those with the fixed-ratio history. The results illustrate the multiple causation of behavior by its previous and current schedules of reinforcement and other concurrent factors.

Key words: behavioral history, adjunctive behavior, polydipsia, historical causation, lever press, rats

Although schedules of reinforcement engender characteristic rates and patterns of responding, these effects may not be the result of only the schedules themselves. Response rates and patterns are sensitive to additional variables, an important source of which is behavioral history (Barrett & Witkin, 1986; Bickel, Higgins, Kirby, & Johnson, 1988; Urbain, Poling, Millam, & Thompson, 1978; Wanchisen, Tatham, & Mooney, 1989).

For example, humans with histories of responding under schedules with interresponse times greater than t (IRT $> t$) exhibit low rates of responding under subsequent fixed-interval (FI) schedules, whereas those with histories of responding under fixed-ratio (FR) schedules typically emit higher response rates on the same FI schedules (Weiner, 1964, 1969, 1970, 1981). More recent research has demonstrated that prior histories of IRT $> t$ and FR schedules of reinforcement will produce differential effects on the FI performance of rats and will also modulate the effects of a tandem response requirement and d-amphetamine on FI performance (Bickel et al., 1988; Urbain et al., 1978).

Although this differential FI responding is a function of schedule history, the means by which schedule history exerts these effects remains largely unexamined. One possibility is the occurrence of adjunctive behavior, a common form of which is schedule-induced responding (e.g., polydipsia). Schedule-induced behavior is engendered and maintained at a high probability as a consequence of reinforcement scheduling, even though it is not required by the contingencies (Falk, 1971). Previous research with rats, for instance, has shown that

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Table 1

Number of sessions in each condition for Manipulation I.

Subject	History: IRT > *t* or FR	FI 15 s: Baseline	FI 15 s: Manipulation[a]	FI 15 s: Baseline
S1	102 IRT > *t*	20	18	62
S2	86 FR 40	24	18	46
S3	69 IRT > *t*	17	18	71
S4	58 FR 40	17	18	30

[a] The order of the water-in (I) and water-out (O) sessions for S1 and S2 was IOIOIIOIOOOIOIOIIO; for S3 and S4, the order was OIIOIOIOOOIOIIOIOI.

Table 2

Number of sessions in each condition for Manipulation II.

Subject	History: IRT > *t* or FR	FI 15 s: Baseline	FI 15 s: Manipulation[a]
S1	28 IRT > *t*	31	24
S2	36 FR 40	19	24
S3	25 IRT > *t*	26	24
S4	25 FR 40	26	24

[a] The order and amount of dose administration (mL) and free-access (FA) sessions during manipulation for S1 and S2 were 5.0 mL/FA/0.0 mL/FA/10.0 mL/20.0 mL/2.5 mL/FA/5.0 mL/FA/0.0 mL/20.0 mL/2.5 mL/FA/10.0 mL/FA/5.0 mL/FA/0.0 mL/20.0 mL/2.5 mL/FA/10.0 mL/FA; for S3 and S4, they were 10.0 mL/FA/2.5 mL/20.0 mL/0.0 mL/FA/5.0 mL/FA/10.0 mL/FA/2.5 mL/20.0 mL/0.0 mL/FA/2.5 mL/20.0 mL/10.0 mL/FA/0.0 mL/FA/5.0 mL/FA.

schedule-induced responding is associated with low rates of lever pressing under IRT > *t* schedules (Laties, Weiss, & Weiss, 1969) and also that IRT > *t* schedules are more likely to produce schedule-induced behavior than are FR schedules (see Falk, 1971; Wetherington, 1982). It follows, then, that behavioral history may exert its effects on the rate and patterning of responding under FI schedules via adjunctive responding.

The present study investigated the role of schedule history and the availability of adjunctive responding on the FI performance of rats. Specifically, rats were given histories of responding on either an IRT > 11-s or FR 40 schedule of reinforcement, with water freely available throughout each session. Subsequently, an FI 15-s schedule was imposed, and water availability manipulated, to determine whether schedule-induced drinking was a means by which schedule history can influence lever pressing. Schedule-induced polydipsia (i.e., excessive drinking) was selected as the adjunctive response because it is easily and reliably generated in rats and shows stability over time; also, more is known about polydipsia than about other kinds of schedule-induced behavior (see Falk, 1971, 1981a, 1981b; Sanger, 1986; Singer, Oei, & Wallace, 1982; Staddon, 1977).

METHOD

Subjects

Four adult male Sprague-Dawley rats (Charles River) were maintained at 80 to 85% of their free-feeding weights. They were individually housed with free access to water in a temperature-controlled (72° F) room.

Apparatus

An experimental chamber (26 cm by 26 cm by 18 cm) was equipped with a response lever, pellet dispenser, food tray, and metal drinking spout. The food tray was centered on the front wall 2 cm above a grid floor; it protruded 3 cm into the chamber. The lever was to the left of the food tray, 3 cm above the floor; each depression of the lever exceeding 0.20 N produced an audible click. The water spout was attached to a 100-mL calibrated reservoir and projected 0.5 cm into the chamber through a circular hole 4 cm to the right of the food tray.

The chamber was contained in a Grason-Stadler animal chest (Model E3125AA-300). A red stimulus light mounted above the food tray provided continuous illumination during the experimental session, an exhaust fan on the side of the chamber provided ventilation and a white noise generator was in operation at all times. The chamber and chest were located in a room adjacent to the area containing the electromechanical scheduling and recording equipment. Data were recorded on electrical impulse counters and a Gerbrands cumulative recorder. Water intake was determined by weighing the calibrated drinking tube before and after the sessions.

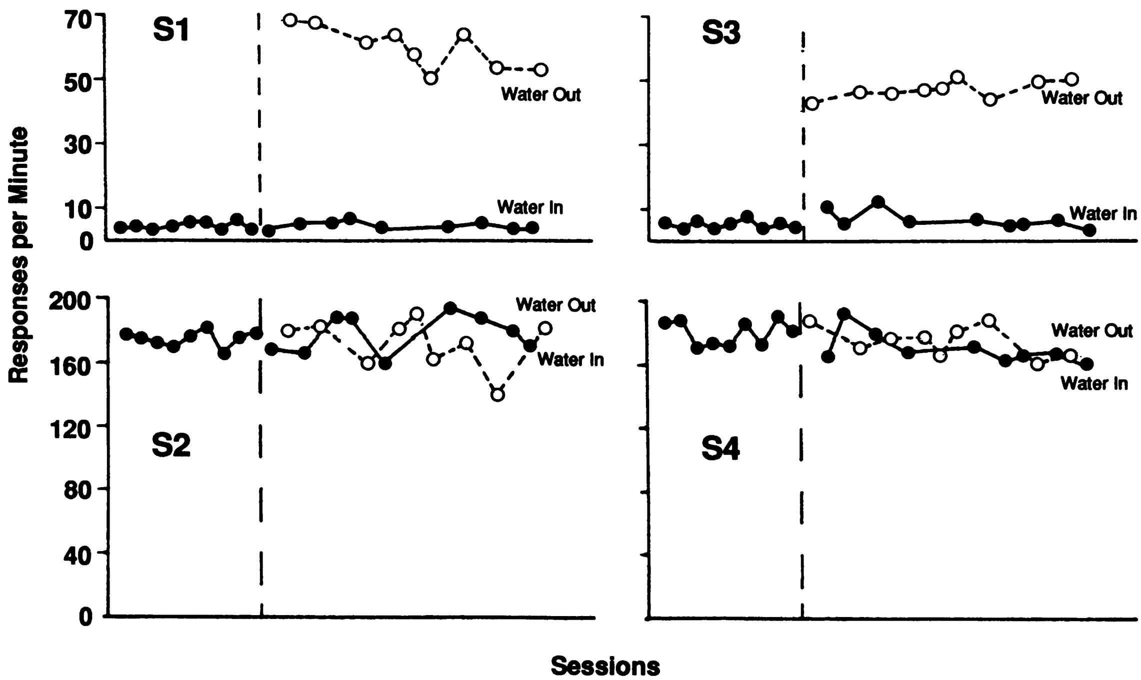

Fig. 1. Responses per minute on the FI 15-s schedule during water-in and water-out conditions. Sessions are presented in order of occurrence, beginning with the final nine sessions of baseline and followed by the 18 sessions of I/O manipulation.

Procedure

Experimental sessions were conducted 6 to 7 days a week at about the same time of day; each session was terminated upon presentation of 30 Bioserve® dustless precision food pellets (45 mg #0021). Two subjects (S1 and S3) were placed initially on an IRT > 11-s schedule, and 2 others (S2 and S4) were trained to lever press under an FR 1 schedule. After steady FR 1 responding was established for S2 (first session) and S4 (second session), their FR requirement was gradually increased to 40 responses. Subjects had free access to a full water bottle throughout these conditions. The conditions themselves constituted the schedule histories for this study.

Responding was considered stable when no increasing or decreasing trends were apparent and when the medians of three successive three-session blocks were within ±10% of the mean for those nine sessions (see Zeiler & Buchman, 1979). In addition, the performance of the subjects with the IRT > *t* history was considered stable only when the number of unreinforced responses was less than two, whereas that of the subjects with the FR history was considered stable only when no pauses were observed in the response runs.

The schedule parameters and stability criteria were selected to produce an approximately equal rate of reinforcement across the schedules and to replicate the behavioral histories in other studies employing rats as subjects (see Bickel et al., 1988; Urbain et al., 1978).

Manipulation I. When the stability criteria were met, the schedules were changed to an FI 15-s schedule (see Table 1). Then, when responding became stable under the FI schedule, the subjects received, in mixed order, a total of 18 "water-in" and "water-out" sessions while the FI schedule was in effect (see Keehn & Riusech, 1979). During water-in sessions, the water bottle was filled; during water-out sessions, the water bottle was in place but empty. After this manipulation, and before the next one, the subjects were returned to the FI 15 schedule with the water bottle filled and in place. The number of sessions in each condition and the order of the subjects' exposure to water-in and water-out sessions are shown in Table 1.

Manipulation II. In the second manipulation, the subjects with the IRT > *t* history were reexposed to the IRT > 11-s schedule, and those with the FR history were reexposed

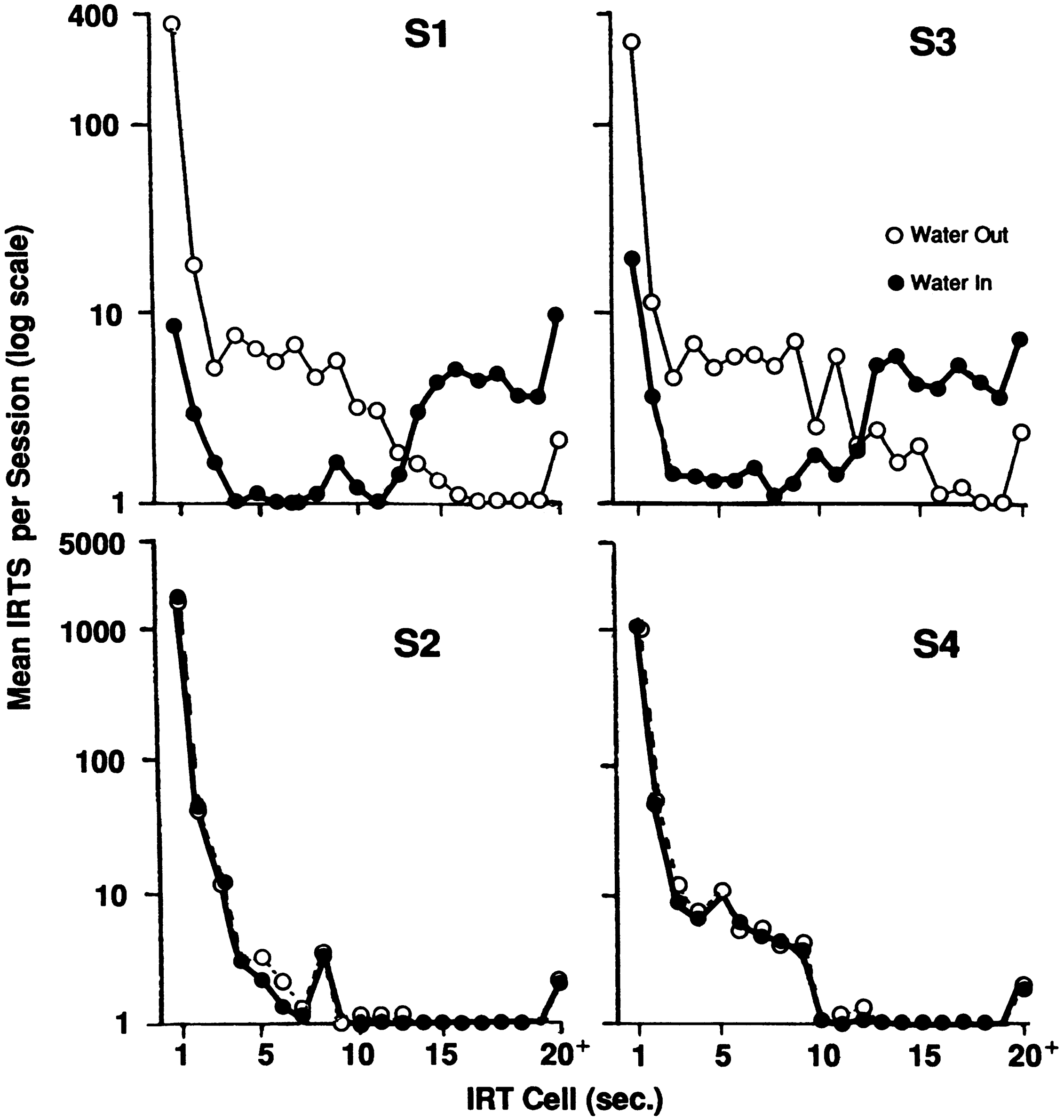

Fig. 2. IRT distributions on the FI 15-s schedule for water-in and water-out conditions. Each point represents the average of 9 days of responding in each condition plus 1.0. The 20th IRT cell represents IRTs of 20 s or longer.

to the FR 40 schedule. After stability was reestablished, the FI 15-s schedule was again put in effect for all subjects. These latter sessions were conducted with 20 mL of water available. After responding became stable under the FI 15-s schedule, the amount of water available in each session—0.0 mL, 2.5 mL, 5.0 mL, 10.0 mL, or 20.0 mL—was changed in a mixed order. A 20-mL session (baseline) occurred at each change. Each of the five levels of water availability was administered three times. The number of sessions in each condition and order of presentation of the varying doses of water are shown in Table 2.

RESULTS

The 2 subjects with a history of responding under the IRT > 11-s schedule (S1 and S3) became polydipsic on that schedule and continued to drink relatively large amounts of water on the subsequent FI 15-s schedule. Their mean water intake per session during baseline,

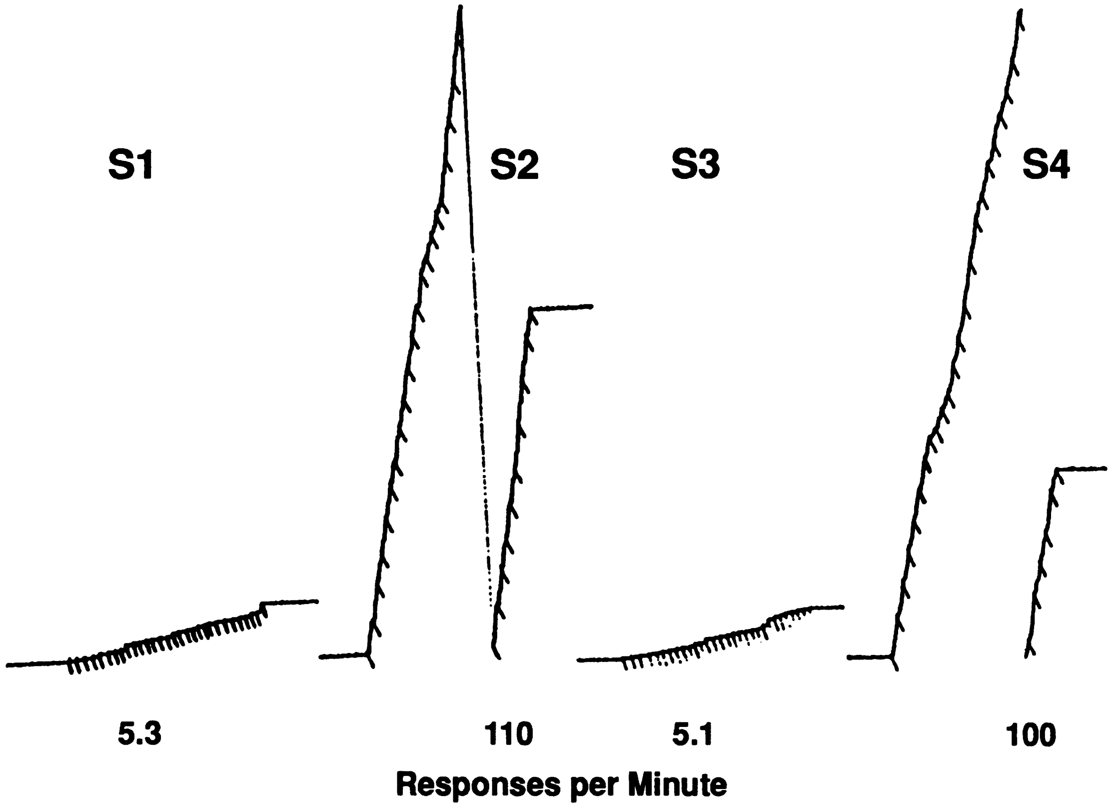

Fig. 3. Representative cumulative records on the FI 15-s schedule taken from the second baseline condition of Manipulation I. The numbers at the bottom of each cumulative record give the response rate for that session.

water-in, and free-access sessions was 15 mL (range, 11–23 mL) and 14 mL (range, 10–21 mL), respectively. The 2 subjects (S2 and S4) with a history of responding under the FR 40 schedule never became polydipsic. Their mean water intake per session across baseline, water-in, and free-access sessions was 0.0 mL and 1.3 mL (range, 0–4 mL).

The obtained rates of reinforcement were similar across all 4 subjects throughout the study once stability was obtained on the IRT > 11-s and FR 40-s schedules (range, 3.0 to 4.6 reinforces per minute). Across all conditions, however, subjects with the IRT > t history (M = 3.3 for S1 and 3.2 for S3; range, 3.0 to 4.3) exhibited somewhat lower reinforcement rates than did subjects with the FR history (M = 3.7 for S2 and 3.9 for S4; range, 3.6 to 4.6).

Manipulation I

Figure 1 shows the responses per minute under the FI schedule during water-in and water-out conditions for all subjects. Sessions are presented in temporal order, beginning with the final nine sessions of baseline (i.e., the sessions in which the stability criteria were met) and followed by the 18 sessions of the water-in/water-out manipulation. Note that the ordinate ranges from 0 to 70 for subjects given the IRT > 11-s history (S1 and S3) and from 0 to 200 for subjects given the FR 40 history (S2 and S4). For Subjects S1 and S3, the mean rates of responding during water-in sessions (4.6 for S1, 6.8 for S3) were similar to baseline rates (4.6 for S1, 5.3 for S3); the mean rates of responding during water-out sessions were considerably higher (57.8 for S1, 47.4 for S3). In contrast, no differences in response rate were observed with respect to water availability for Subjects S2 and S4. Their rates of responding during baseline, water-in, and water-out sessions were high and steady in all conditions.

Figure 2 presents IRT distributions (in 20 1-s bins) on the FI schedule during water-in and water-out conditions for all subjects. Each data point shows the mean number for the nine sessions. The 20th IRT cell includes IRTs of

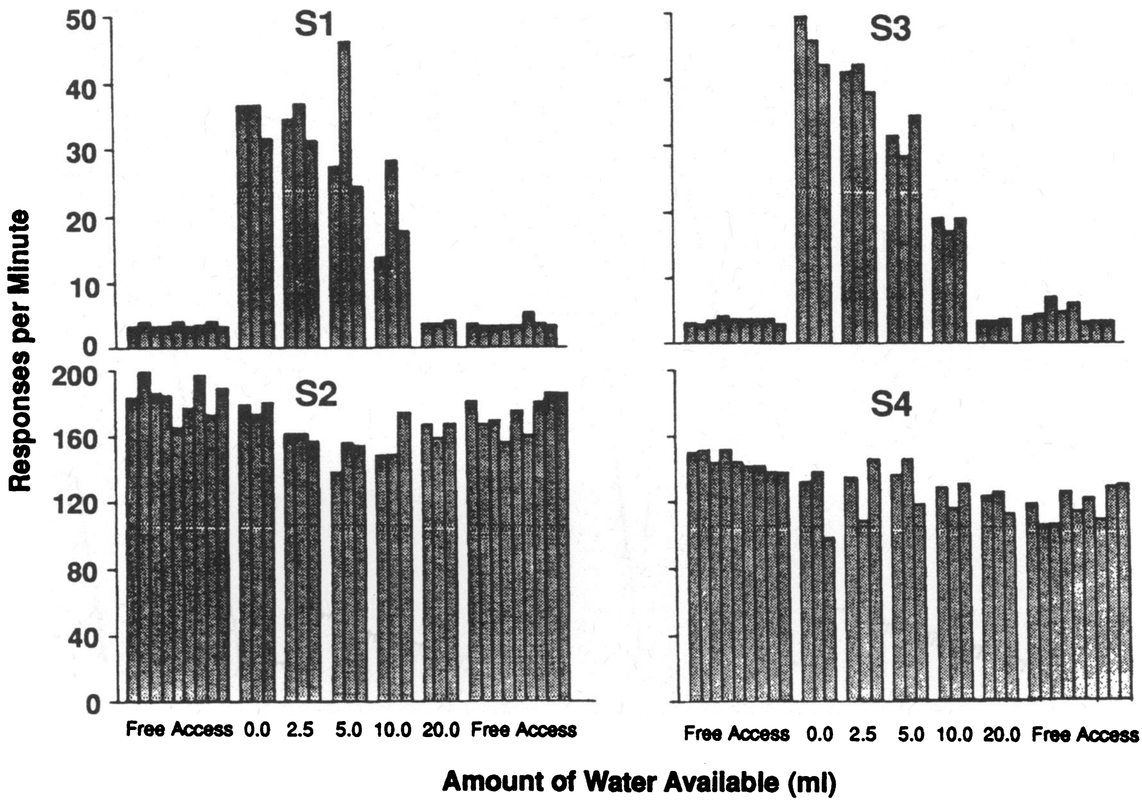

Fig. 4. Responses per minute on the FI 15-s schedule as a function of the availability of varying doses of water. Each bar represents one session. Bars within each category are in temporal order of administration. The free-access sessions on the left of each graph represent baseline sessions prior to the beginning of the manipulation; those on the right represent free-access sessions that occurred during the manipulation.

20 s or longer. Because the average for some IRT bins was less than 1.0, the data were transformed by adding 1.0 to each mean; the data were plotted on a log scale because of the frequency of short IRTs.

Water availability for Subjects S1 and S3 produced very different IRT distributions, but for Subjects S2 and S4, water availability had no effect on the IRTs (Figure 2). Between-subject variability under each schedule-history condition was minimal; the IRT distributions for subjects with the same history were almost identical.

Figure 3 shows representative cumulative records of responding on the FI schedule for all 4 subjects. Note that the characteristic IRT $> t$ and FR behavior continued for many sessions of the FI schedule.

Manipulation II

Response rates under the FI 15-s schedule are shown in Figure 4 as a function of the amount of water available. Each bar represents one session; bars within each category are in temporal order of administration. The free-access sessions on the left of each graph represent baseline sessions prior to the beginning of the manipulation; those on the right represent the free-access sessions during the manipulation. Note that the ordinate ranges from 0 to 50 for Subjects S1 and S3 and from 0 to 200 for Subjects S2 and S4. Whereas the water manipulation produced no differences in the response rates of subjects given the FR history, clear differences were found in response rates of subjects given the IRT $> t$ history. The latter response rates were inversely related to the amount of water available.

Figure 5 shows IRT distributions on the FI 15-s schedule for each level of water availability. Each point represents the average of three administrations of that level under each condition (i.e., three sessions) plus 1.0. The

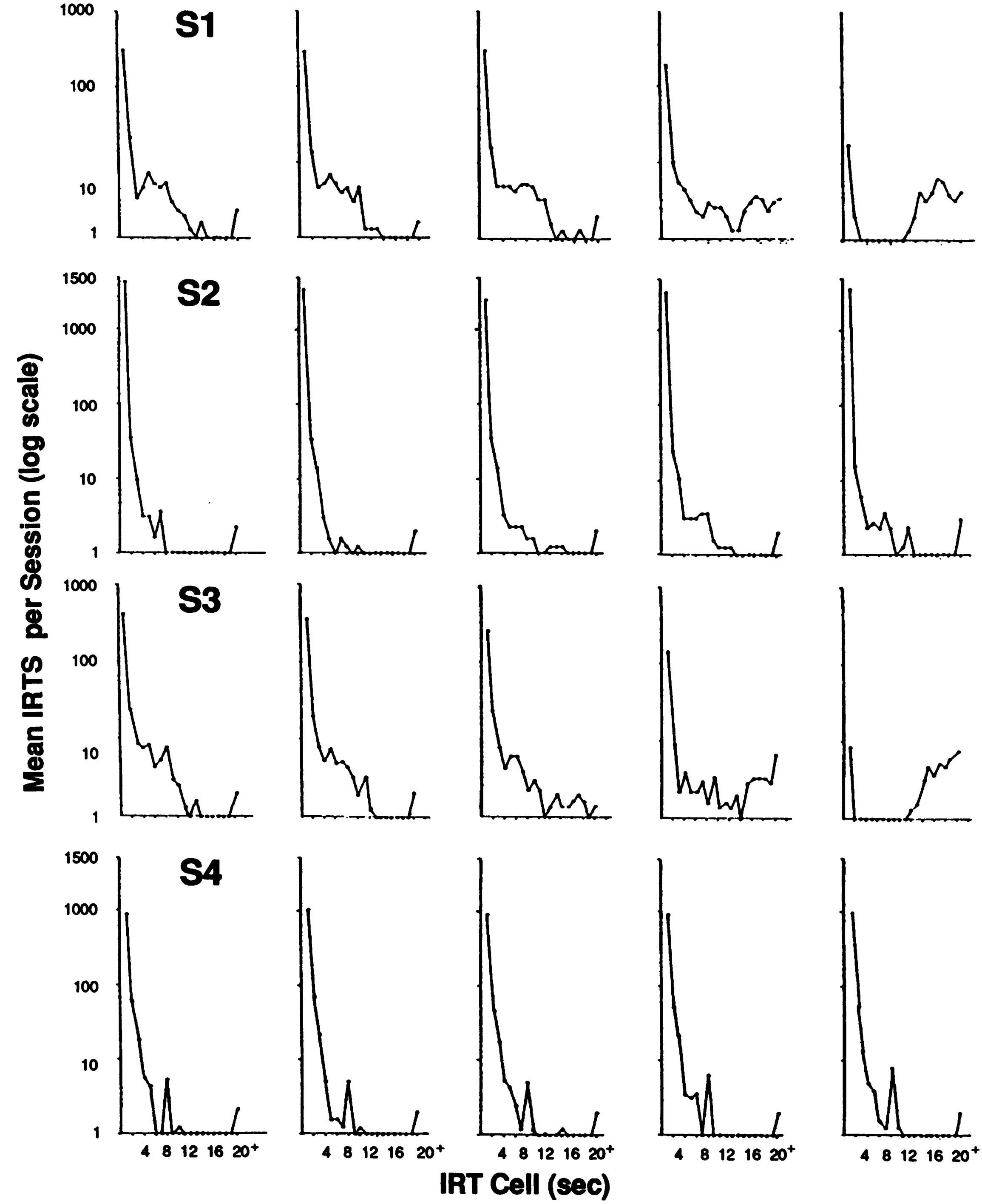

Fig. 5. IRT distributions on the FI 15-s schedule for each level of water availability. Each point represents the average of three administrations of that volume (i.e., three sessions) in each condition plus 1.0. The 20th IRT cell represents IRTs of 20 s or longer.

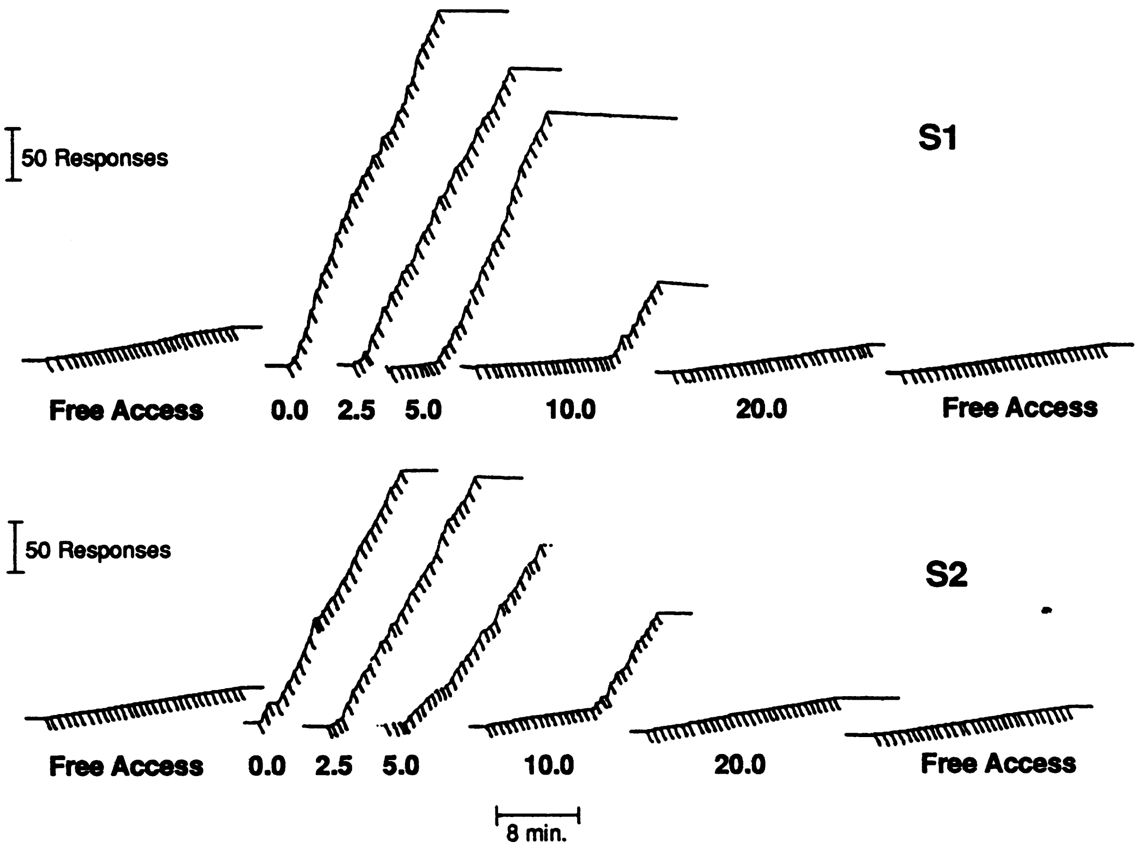

Fig. 6. Representative cumulative records on the FI 15-s schedule for subjects given an IRT > 11-s history for free access and for each level of water availability. Free-access sessions on the left represent baseline sessions prior to the beginning of the manipulation; those on the right represent sessions that occurred during the manipulation.

20th IRT cell includes IRTs of 20 s or longer. As in Figure 2, responding was consistent across subjects in relation to their schedule history.

The representative cumulative records in Figure 6 show the FI performance of subjects with IRT > 11-s histories during each level of water availability. Free-access sessions on the left represent baseline sessions prior to the beginning of the manipulation; those on the right represent the sessions during the manipulation. During a single FI 15-s session, both high and low response rates were produced by individual subjects, especially at the 10.0-mL dose.

DISCUSSION

These results demonstrate that IRT > *t* and FR schedule histories significantly influence behavior under a subsequent FI schedule. Following the IRT > *t* history, the amount of water available produced large changes in the rates and patterns of FI responding; no such effect occurred for the subjects with the FR schedule history. These findings are in accord with the results of prior studies conducted with both rats and humans (Bickel et al., 1988; Wanchisen et al., 1989; Weiner, 1964) and extend those findings by identifying a mechanism—schedule-induced behavior—through which schedule history influences behavior.

The findings are also consistent with those of a previous report on the effects of adding a tandem response requirement to high- and low-rate FI performance under the same schedule parameters investigated in the present study (Bickel et al., 1988). In that study, the development of polydipsia was delayed in 1 rat with an IRT > *t* schedule history; this rat exhibited higher FI response rates than did the rats who had become polydipsic on the IRT > *t* schedule. Once polydipsia developed in this rat, however, his response rates under the FI decreased to levels comparable to those of other subjects. The results of the two studies suggest that schedule-induced drinking may be one way that schedule history exerts its effects on subjects with IRT > *t* histories. That water availability did not influence FI performance of rats who had FR histories, however, indicates that still other factors are involved in the interaction of schedule history with subsequent responding.

The present results also show that schedule history can interact with variables controlling ongoing schedule performance. In these cases, schedule history may affect behavior in ways similar to that in the behavior–behavior interactions observed in other experimental arrangements. The presence of a concurrent schedule, for example, can markedly influence schedule-controlled behavior (Poppen, 1972). Relatively high rates of responding occur under FI schedules when concurrent IRT > *t* schedules are in effect, whereas low rates occur in the presence of concurrent FR schedules. Future research should examine the relationship between the effects of schedule history and the behavior–behavior interactions generated via these different operations.

In the present study, the effects of schedule history were robust and well maintained, in contrast with the findings of the study by Urbain et al. (1978), in which the schedule-history effects were transient. This discrepancy may be due to two differences between the studies. First, subjects in the present study were maintained in the IRT > *t* and FR conditions until stringent stability criteria were met (58 to 102 sessions). In contrast, those in the Urbain et al. study were moved to the FI condition after 50 sessions, independent of their behavior at that point. The absence of a behavioral criterion for stability may have resulted in more variable responding, and hence in the dissipation of the effects of the schedule histories. Second, Urbain et al. administered *d*-amphetamine, which may have modulated the effects of the schedule histories. If *d*-amphetamine functions in this manner, this suggests an interesting preparation for examining the effect of drug-history interactions on behavior (see Egli & Thompson, 1989; Wanchisen, 1990).

These results illustrate that the determinants of behavior act multiply and interdependently, and that the relationships among them may be of greater importance than the character of any one in isolation (McKearney, 1979, 1981; McKearney & Barrett, 1978). More specifically, generalizations about the effects of particular reinforcement schedules across contexts may be unwarranted if schedule history is overlooked. Conversely, although schedule history can be important, its influence can be modulated by current schedule conditions (e.g., Ferster & Skinner, 1957). Further, even when past and present schedule conditions are held constant, changes in behavior can be influenced by still other aspects of the organism's environment (e.g., the availability of an adjunctive response). Behavior, then, is a function not only of its current schedule of reinforcement but also of its schedule history and still additional factors (see, e.g., Barrett & Witkin, 1986).

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